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An Agent-Based Framework for Persuasive Health Behavior Change Intervention

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Abstract. With the increased understanding of human behavior and the systematic reporting of a different mechanism through which the behaviors can be influenced, autonomous coaching systems are emerging. In this paper, a generic framework, based on the behavior change ontology, for health behavior change support systems is presented. In the framework, all the intervention components are singly defined and linked. The BDI-based behavior change coaching agent is designed through a framework which delivers behavior change intervention for a variety of coachees (human). Physical activity coaching scenario is created and simulated to show the definition and implementation of different classes in the framework. The simulation results show how through this framework we can define a coaching agent that can apply different types of health behavior interventions across a population of coaches and their preference settings.

Keywords: BDI based agent · Health behavior change · Physical activity · Health behavior framework · Health behavior coach

1 Introduction

The design of digital behaviour change systems and barriers to effective persuasive technologies for a healthy lifestyle are still lacking a unified theory, interdisciplinary awareness, accepted design models, and a common terminology [1]. Recent ontology related to behavior change intervention is defined by combining different classes and their relationships (i.e. Behavior change techniques (BCTs), Mechanisms of Actions (MoAs), behavior, context etc.) gives a common vocabulary and an opportunity to researchers to participate and use ontologies more effectively in their research [2, 3]. In spite of the progress being made, the limited collaboration between technology designers and the health behavior experts usually leads to technologies that are poorly designed or the selection of the health behavior theories are not appropriate or the theory and models selected are not flexible enough to cover all the aspect of the target behavior [4]. The new challenges of this field require new technologies that facilitate the construction of more dynamic, intelligent, flexible and open applications, capable of working in a real-time environment. A generic framework based on the ontologies and theories of behavior change to design a behavior change support systems could be beneficial. The framework

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would not only provide an opportunity to define design coaching agent but also help design and evaluate a different kind of health behavior interventions.

The recently published ontology for behavior change interventions (BCIO) proposed by S. Michie in *Human behaviour change project* (www.humanbehaviourchange.org) offers a basis for the development of the framework, where the features of an intervention and its relationship were defined. An ontology is a taxonomic description of the concepts in an application domain and the relationships among them. It asserts the characteristics of interventions (i.e., their content and delivery) that are related to behavior through designated mechanisms of action [3].

The framework is generic in the sense that any kind of coaching agent and health behavior change intervention can be defined thought it, because all the common component of behavior change intervention, for example, behavior change techniques (BCTs), mechanism of actions (MoAs), context, mode of delivery etc. are defined and causally linked. All the components within the framework are defined in the section below. Moreover, a BDI-coaching agent published in our earlier paper [5], is implemented as a digital behavior change support agent with a different type of coachee agents, through the framework. The coach identifies strength and weaknesses of the subject, generate a training plan, motivates and helps, just like a human coach. Such a digital coach will highly benefit from the activity tracking system data which is used to personalize the training plan based on performed activities. BDI (Belief, Desire, Intention) agents' paradigm [6] have been presented extensively in the literature, but so far few have elaborated on the adoption of the BDI architecture for health behavior, as proposed in this paper.

Based on this implementation and simulations of digital behavior change support coach and different coachee (human) that it is possible to model a variety of individuals, as well as different types of interventions with multiple active ingredients (i.e. Behavior change techniques). Moreover, the separation of BCTs and MoAs gives an opportunity to plug & play multiple behavioral models from literature which can then be simulated.

The rest of the paper is organized as follows. Section 2 describes the health behavior change support framework and its main components. Section 3 shows the physical activity coach model based on this framework. The implementation of the coach is used in a simulation, and results are described in Sect. 4. Finally, the last section contains a conclusion.

2 Health Behavior Change Support Framework

In this section, we proposed an agent-based generic framework based on the ontology of behavior, which assists the designer to develop and simulate the health behavior change support system with a clear understanding of all the components and the process (see Fig. 1). The main components are the environment & context, intervention, mechanism of action, and the coach and coachee are included to make clear differentiation of each component class. The definition of each of the component is given below.

2.1 Environment and Context

The elements in this component act as input variables and define the intervention and simulation environment for autonomous coaching agent. The context is for defining the

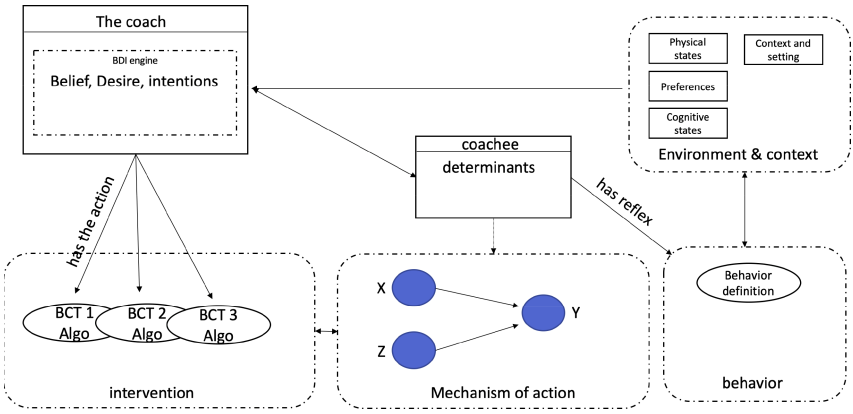

Fig. 1. The BDI-based agent framework for persuasive health behavior change.

target population and setting. Similarly, other variables like coachee (human) preferences physical states etc. can be defined but it all depends on the intervention. For example, in the case of physical activity intervention, motivation, blood pressure, weather, location etc. can be used to define context and environment.

2.2 Intervention

Intervention is a generic term which includes product, service, activity or structural change, intended to achieve behavior change. It can be specified in terms of the content of the intervention and the way this is delivered. In our case, these contents and structure are defined as the function of the coaching agent. For example, in the case of physical activity intervention enforcing self-monitoring, goal-setting, reward delivery etc. can be seen as intervention content.

2.3 Mechanism of Action

Mechanisms of action (MoA) is conceptualized as a range of theoretical constructs, defined broadly as 'the processes through which a behaviour change technique affects behaviour'. These link between BCT and mechanism of action can be easily derived from the heat map given at [7, 8].

Moreover, the links between BCTs and MoAs are important for simulation because the important part in simulation is showing the exact effect of the BCT (i.e., evaluating the processes through which BCTs have their effects).

3 The Physical Activity Coach – Implementation

This section describes how the components defined in the framework above can be used to implement a physical activity coach. BDI architectures have been introduced in several agent-based modelling and simulation (ABMS) platforms. For example, the BDI paradigm integrated into the GAMA modelling platform using its GAML modelling language [9]. We have chosen to implement our coaching agent in GAMA platform.

3.1 Description of the Coaching Scenario

The coaching agent is able to provide three different BCTs as listed in the taxonomy [10] (i.e. 1.1. Goal setting behaviour, 2.2. Feedback on behaviour and, 10.10. Reward on the outcome). According to the framework (see Fig. 1), the effect of these interventions may increase the likelihood of a coachee making an increase physical activity (behavior) by raising motivation and intention about the health risks from not being physically active (mechanism of action). This implementation is composed of 5 steps. The five steps (i.e. coachee and its determinants, environmental & contextual variables, defining intervention, defining mechanism of action, and definition of the BDI coach) are explained with its purpose and explicit formulation.

Creation of Coachee, Environment and Context Variables. We designed a generic behavior model (Fig. 2) as a temporal causal model. The constructs used in this model are based on some well-known established psychological theories of behavior change. For example, self-efficacy and outcome expectations from bandura social cognitive theory; defined as confidence in one's own ability and control over the outcome expected to carry out a particular behavior [11]. Similarly, the health belief model and behavior change wheel define motivation as one of the main construct driving behavior [12, 13]. According to the theory of planned behavior [14], intentions plays an important role to perform behaviors and can be predicted by a number of different kind of behavior constructs and, finally, the goal-setting theory [15] explain the human behavior as "introspective observations" of itself and very much driven by the goal it set for him/herself.

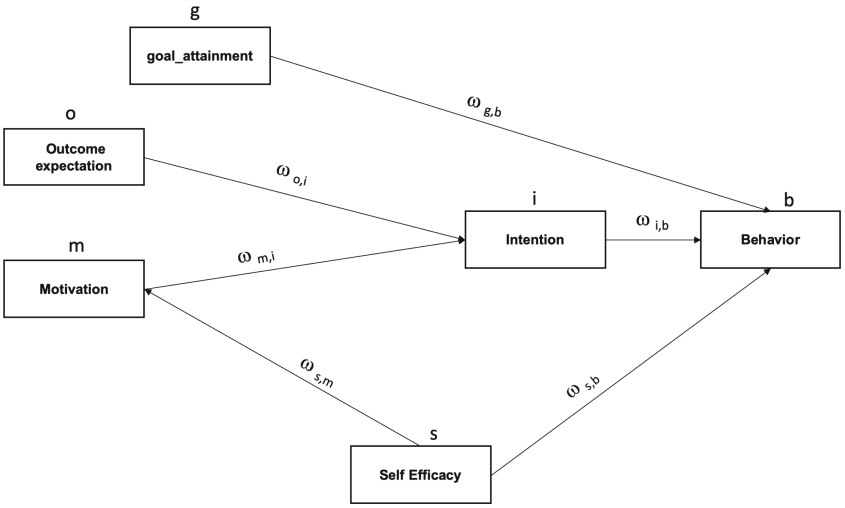

Fig. 2. Generic behavior model for all coachees. The behavior of each coachee will be defined by the construct and connection values.

The motivation and intentions are the compound constructs and they are formalized as follow:

Motivation (m). Motivation is implemented by updating its value with the incoming connection from self-efficacy(s) with a weighted average function to contain it within the range of [0–1]. The symbol $\omega_{s,m}$ represents the connection weight between self-efficacy and motivation. The higher the weight is, the higher would be the impact.

$$m(t+1) = m(t) + ((1 - m(t)) * s(t) * \omega_{s,m}) \tag{1}$$

Intention (i). The intention is a key driver in coachee behavior and influenced by a number of constructs. The symbol $\omega_{o,i}$ & $\omega_{m,i}$ represents the connection impact of outcome expectation and motivation on intention. It is mathematically formulated as follow:

$$i(t+1) = i(t) + ((1 - i(t)) * ((e(t) * \omega_{o,i}) * (m(t) * \omega_{m,i})) \tag{2}$$

Behavior (b). The specific target behavior here is daily step count and it depends on a number of socio-ecological constructs for that reason we generate number a random step between 4000 to 6000 and further influenced by the constructs defined in Fig. 2. The formulation is as given below:

$$b(t+1) = ((i(t) * \omega_{i,b}) + (g(t) * \omega_{g,b}) + (s(t) * \omega_{s,b})) * \text{rand}(4000, 6000) \tag{3}$$

We considered three types of agents (human), that are *Red Coachee, Blue Coachee, and Green Coachee.* The initialization for the different coachees and their properties would be defined according to the scenario in the simulation section below. To show the difference, we considered different contextual and intervention variables with different values, which are defined as: window size (9), Percentile (0.6), Total no. days (70), Phase A days (10), and Intervention days (42). The psychological constructs for coachee are intention, out come expectation, self-efficacy, goal attainment, motivation, sensitivity to goal setting, sensitivity to rewards, and sensitivity to feedback on behavior.

Defining Intervention. The simple intervention is applying an adaptive goal setting and reward BCTs to increase daily step counts. The next day goal is based on previous days observed behavior and if the goal is achieved, the coachee is rewarded, otherwise not. To observe the behavior before intervention and calculate average steps count, we established 10 days baseline phase, called as phase A.

Adaptive Goal Setting Algorithm. The adaptive goal-setting algorithm is based on a rank-order percentile algorithm derived from recent developments in basic science around schedules of reinforcement [16]. The algorithm works as follow:

The observed behavior (steps/day) is ranked from lowest to highest and calculation of a new goal based on a *pth* percentile criterion. For example, for one participant, the steps count, each day for their last 9 days (ranked from lowest to highest) was List(L) = 10000, 12000, 13000, 14500, 15000, 15700, 16300,164000, 169000.

The 60th percentile represents a goal of 15700 steps, which becomes the 10th day's goal. Based on [16], the best window size and percentile to consider for physical activity behavior is of 9 and the 60 percentile.

Reward on the Outcome. Rewards are arranged, if and only if there has some effort (or) progress in achieving the behavioral outcomes. The coaching agent delivers a point if and only if the coachee agent achieves the goal set on any certain day.

Defining Mechanism of Actions. The impact of intervention may be affected by the intervention content or mode of delivery and modelling this effect need more research and modelling. For example, some coachee may be reluctant to subject themselves to static goal-setting leading to low physical activity or maybe demotivated with rewards if they found less or unwanted. To make our a very simple mechanism of action we model three different mechanism of action for each of the BCT are explained.

According to [8], the "goal setting" behavior change technique works by instigating the goal attainment and intention process of the person. Similarly, the feedback and reward-based behavior change techniques exhilarate outcome expectation and motivation and self-efficacy and motivation respectively. They are mathematically formulated so that they can be constrained within the range of [0,1].

The behavior model described above predicts the daily steps count of the coachee with the help of psychological constructs. Now when the goal setting is applied, the behavior of coachee changed (means something in the model is changed). That change is presented with these functions.

BDI Based Coaching Agent. The implementation description of the BDI components of the physical activity coach are given below:

Beliefs. Beliefs are represented as predicates in GAML language. Perception is a function executed at each iteration to update the agent's belief base. For example, when the red coachee is perceived, a new belief is added about the steps taken today. The rule is applied when the belief about today step count is updated, a new desire "red_today_steps" is generated.

Goals/Desires. The BDI model assumes that agents are driven by goals. The objectives that the agent would like to accomplish, are updated during the simulation following a goal-plan tree. The desires that the coaching agent can have are represented in Fig. 3.

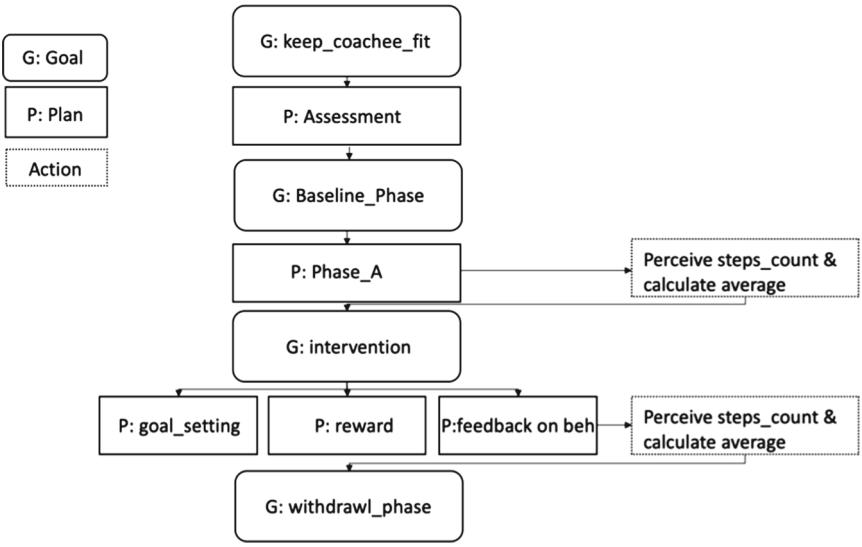

Fig. 3. The goal-plan tree

4 Simulation

Different simulations are performed to investigate the implementation and working of the framework.

4.1 Goal Setting and Reward to Increase Physical Activity

In this part of the simulation, the BDI-based coaching agent applies adaptive goal setting and reward BCT to coachees, to increase their physical activity. All the construct values and connection values are initialized with the same value (e.g. 0.1 and 0.5 respectively), expect the value of 'outcome expectation', which are having values: Red coachee (0.3), Blue coachee (0.5), Green coachee (0.7). As each human are different in nature so as their sensitivity to different intervention. The variation in the sensitivity to goal-setting BCTs is red coachee (0.1), blue coachee (0.4), green coachee (0.9). The values are just assumed randomly for simulation purposes.

The coaching agent applies goal setting and sets an adaptive goal for each next day in the intervention phase and rewarded points to those who achieve its goal. In Fig. 4 it can be seen that the average step count of blue coachee was the highest of three in phase A, but when the goal setting is applied during the intervention phase, the average step count of green coachee increased and became the highest. The increase is due to the high sensitivity of the green coachee to goal setting BCT in comparison to the other two coachees. To see how goal setting actually worked within the coachee (MoA), we can look at the change of the values of their internal concepts. In Fig. 5 it can be seen that goal setting increased the intention and goal attainment determinants of the coachee which leads to increase in their average daily steps count. In Table 1, it can be seen that blue coachee achieved more of its target, so in return, the reward is awarded, which

triggered its motivation and self-efficacy (reward mechanism of action). In Fig. 6, it can be seen that the blue coachee self-efficacy and motivation get increased, because he/she achieved more goals. Hence the result shows how different types of coachees, their responses to a different type of intervention, and the effect of these interventions can be simulated.

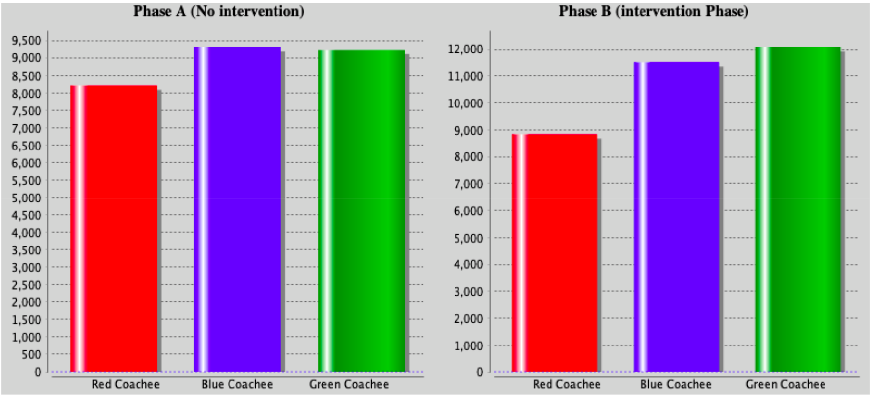

Fig. 4. The average steps taken by the three coachees, before and after applying goal setting and reward BCTs. (Color figure online)

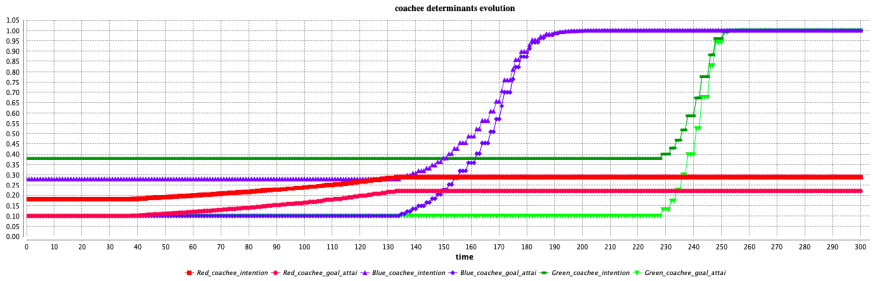

Fig. 5. The evolution of the goal attainment and intention determinants. (Color figure online)

4.2 Feedback on Behavior to Increase Physical Activity

To show how different kind of behavior model can be plugged-in or replaced, we replaced the behavior model, used in Sect. 3.1, with the theory of planned behaviour, which is a well-established social– psychological theory that is used to examine human intentions and behaviour in situations where individuals might lack control over their own behaviour (see Fig. 7). Key construct is behavioral intention, which represents what would motivate and influence users to act in certain behaviours, which in turn influenced by attitude, subjective norm and behavioral control. The best reported BCT for

Table 1. The effect of goal setting on steps count before and after the intervention and the number of times the coachee achieves the goal.

Coachee	Average steps count		Increase percentage	No. of times goal achieved
	Before	After		
Red coachee	8207	8833	7.62%	20
Blue coachee	9315	11503	23.48%	22
Green coachee	9226	12084	30.97%	15

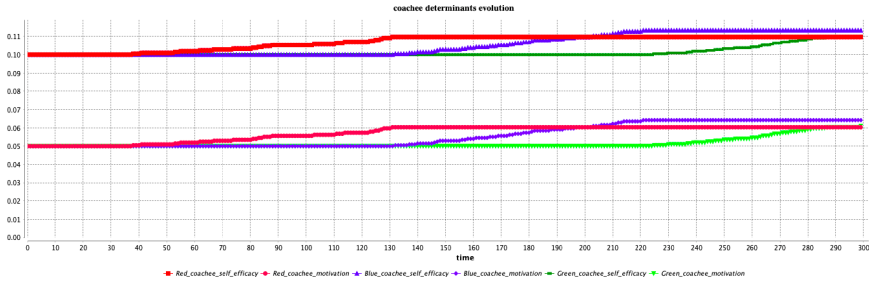

Fig. 6. The evolution of self-efficacy and motivation determinants. (Color figure online)

targeting the "perceived control" determinant is the feedback on behavior. We defined the sensitivities of red, blue, green coachees toward feedback BCT as 0.85, 0.17, and 0.02, respectively.

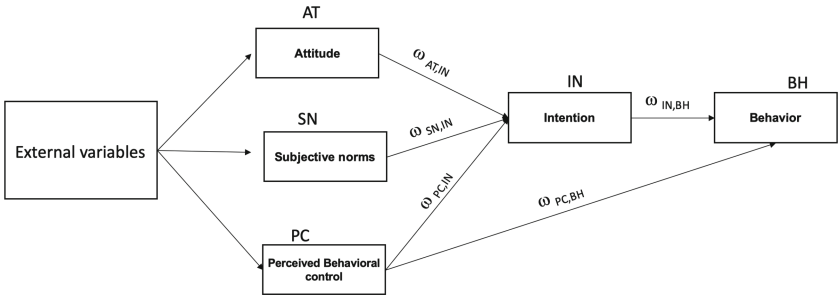

Fig. 7. Theory of planned behavior

In the above coaching agent implementation, we developed our own behavior model that is based on SCT, HBM, and Goal setting theories. This model is basic and is not validated. However, in this framework, several types of models can be used. For example, the COMBI model [17] can be used in the assessment stage to identify the problematic determinants. The identification of problematic determinant(s) can then help in choosing the right kind of behavior change technique in the intervention phase. We used the theory of planned behavior to predict the behavior of the three coachees and with the feedback

on their behavior we are trying to influence their control over behavior. Figure 8 shows that the red coachee performed well on feedback, its due to its high sensitivity to feedback and resultantly, Fig. 9 shows the increase in perceived control of the different coachees. So, the result shows how we can plug & play with different kind of theories.

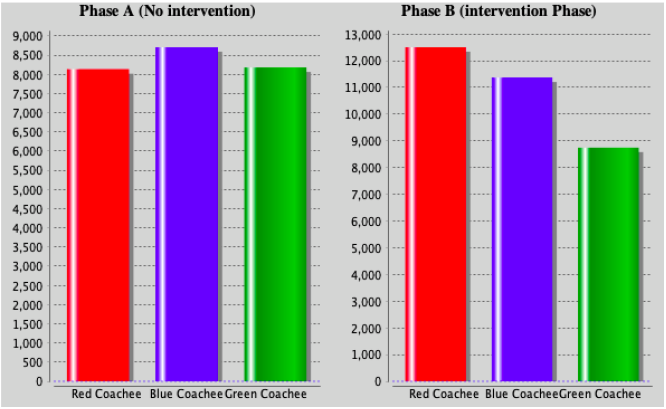

Fig. 8. Average steps count before and after applying feedback BCT. (Color figure online)

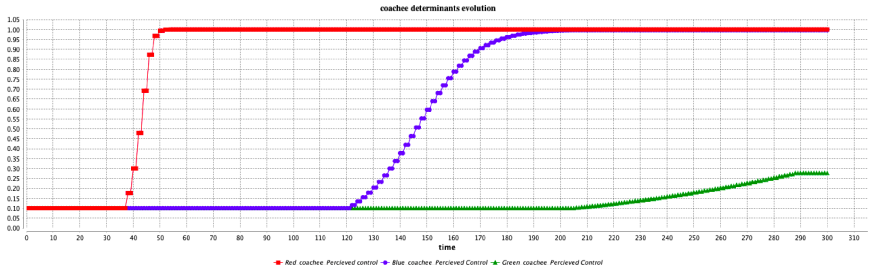

Fig. 9. The evolution of the construct "perceived behavior control" due to intervention. (Color figure online)

5 Conclusion

This work presents the extension and implementation of a BDI based generic coaching agent framework. The framework makes use of the behavior change intervention ontology (BCIO). It has a clear separation between the behavior change techniques and the mechanism of actions through which these techniques work. The working of the framework has been shown by implementing a physical activity coaching agent, which has a strong potential of providing support for different types of individuals with respect to their context and environment. Multiple intervention types of interventions can be defined within the framework, each having their own active ingredients and models.

The coach agent was designed with a specific behavior prediction model and specific BCT to increase daily step counts. Obviously, the model is only a simplified representation of actual human behavior and randomness is used to represent variance between individuals. Human behavior is the interaction between various ecological, psychological, and environmental components, so the framework is so flexible that any type of complex behavior model and separate intervention components and be explicitly defined.

In future, we intend to validate the model by setting up experiments with real users. A mobile or web-based interface would be created to deliver the content of the intervention to the group of people selected for intervention. The experiment would be on the real-time data collected through different mobile sensors or wearables. The intervention design and contents would be developed with the help of the field experts. The intake and the intervention result would be compared with the simulation result for validation. This framework would give us an opportunity to define and validate new hypothesis about the applicability of just-in-time adaptive interventions (JITAI) and also can help vary across types of intervention, contexts and environments.

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